5. [Cancel]

6. [Cancel]

7. [Cancel]

8. [Cancel]

9. [Cancel]

10. [Cancel]

11. [Cancel]

12. [Cancel]

13. [Cancel]

14. [Cancel]

15. [Cancel]

16. [Cancel]

17. [Cancel]

18. [Cancel]

19. [Cancel]

20. [Cancel]

21. [Cancel]

22. [Cancel]

23. A process for creating an instability mechanism for rapid and homogeneous mixing of one or more fluids comprising:

(a) introducing one or more fluids into a mixing chamber having a specific geometry for enhancing and producing corners 0000in said mixing chamber for creating corner vortices, and having one or more inlets for receiving said fluids and at least one splitter plate having a trailing edge and configured to create corners in said mixing chamber and to create a shear layer between said fluids;

(b) separating said fluids on entrance into said mixing chamber by said splitter plate creating primary vortices at said trailing edge of said splitter plate;

(c) forcing said shear layer between said fluids through the periodic application of a narrow frequency band, said shear layers having a specific receptivity to said narrow frequency band, and independent of said fluid's velocity into said mixing chamber; and

(d) creating enhanced streamwise vortices for enhanced mixing through the interaction between corner vortices and said primary vortices.

24. A process for creating an instability mechanism as claimed in claim 23 wherein said frequency band is generated by a means selected from the group consisting of a forced flap in said trailing edge of at least one splitter plate, a forced membrane, a piston pump and a periodic valve upstream of said trailing edge of at least one splitter plate for forcing the mixing of at least one fluid stream.

Discussion of Claims

Examiner states that claims 12 to 22 are rejected as being unpatentable over Wygnanski. Agent for Applicant respectfully submits that claims 3 – 22 have been cancelled from the application, and that claims 23 and 24 have been added. Examiner states that the Applicant's arguments regarding Wygnanski did not address any particular claim or point out the differences between the positively

recited steps as claimed and Wygnanski. Agent for Applicant respectfully submits the following analysis of the claimed invention and Wygnanski.

In claim 1 Wygnanski claims a method of controlling the mixing of two fluids of the same state or of substantially the same state in a mixing region having a flow axis. The two fluids are directed to contact one another at the beginning of the mixing region. An active element is driven to induce oscillations of the two fluids about an axis substantially normal to the flow axis in the vicinity of the beginning of the mixing region. The result of the process is that small flow fluctuations occur perpendicular or normal to the flow axis at the boundaries of the mixing region.

More specifically, Wygnanski uses an active element to induce small fluctuations in the flow of the two fluids, which are substantially normal or perpendicular to the flow axis at the boundaries of the mixing region. It is these small fluctuations or small velocity perturbations, which contribute or cause the inherent instability of the flow of the two fluids and therefore enhance or control the mixing of the fluids. This inherent instability of the flow or instability mechanism contributes to Wygnanski's method and is what is intended to be within the scope of claim 1 (U.S. Patent '244 cols. 1 and 2 lines 64-68 and 1-6 respectively).

More specifically, the method disclosed in Wygnanski is today well-known based on Kelvin-Helmholtz instability mechanism (see articles from Ho & Huerre 1984, and Fiedler & Fernholtz 1990) for more information which allows for controlled enhanced mixing that is twice as efficient (U.S. Patent '224 col. 4 lines 58-66). Specifically, Wygnanski used the spreading rate of the mixing layer of the two streams to illustrate the importance of the frequency of the active element, coupled with determining the boundaries of the mixing layer or width of the mixing layer by differing the velocity of the two fluids to control the mixing process and double the mixing rate. Figure 1 of Patent '224 illustrates the mixing process and that the mixing of the fluids improves when the boundaries or spreading angle of the mixing layer, (which are wedge shaped), increases. The wedge shape or spreading angle disclosed in Wygnanski reflects the results of the doubled efficiency of the mixing

process. Clearly from the figures and the description, the enhanced mixing occurs downstream of the trailing edge of the splitter plate (Figure 4b) as a preferred frequency is applied which is determined by the mean velocity of the fluids.

Wygnanski also demonstrates the saturation phenomenon namely, when the amplitude increases to a certain point, there is no influence on mixing enhancement. This is implied in Figure 5 (U.S. Patent '224), where the value of the forcing amplitude increases the influence of the forcing amplitude or the velocity perturbation decreases. It is also well-known that once there is sufficient forcing amplitude, any further increases of forcing amplitude will have no effect for mixing control (see from Fiedler & Mensing 1985). Therefore, a lower velocity perturbation is usually required which means a smaller amount of energy is used (U.S. Patent '224 col. 2 lines 37 – 42).

Furthermore, the configuration of the method is preferably axisymmetric, i.e. annular or taurus shaped, in other words a shape that is devoid of corners (U.S. Patent '224 col. 3 lines 42 – 46).

Wygnanski concludes that depending on the desired control of mixing, there is a preferred frequency for each case depending on the configurations of the method and velocities of the fluids (U.S. Patent '224 col. 4 lines 41 - 47). Therefore Wygnanski's invention focuses or claims a method for the interaction of the two fluids and the application of an active element (frequency and amplitude) on these two fluids within a boundary that is determined by the velocity of the fluids.

Agent for Applicant respectfully submits that new claim 23 claims a process or method for creating an instability mechanism for rapid and homogeneous mixing of one or more fluids. The result of this method or process is that the creation of the instability mechanism results in enhanced streamwise vortices and dramatically enhanced mixing from the creation of enhanced corner vortices due to the specific geometry of the mixing chamber and the configuration of the splitter plate (passive influences). Furthermore, the application of active forcing of a narrow frequency

process. Clearly from the figures and the description, the enhanced mixing occurs downstream of the trailing edge of the splitter plate (Figure 4b) as a preferred frequency is applied which is determined by the mean velocity of the fluids.

Wygnanski also demonstrates the saturation phenomenon namely, when the amplitude increases to a certain point, there is no influence on mixing enhancement. This is implied in Figure 5 (U.S. Patent '224), where the value of the forcing amplitude increases the influence of the forcing amplitude or the velocity perturbation decreases. It is also well-known that once there is sufficient forcing amplitude, any further increases of forcing amplitude will have no effect for mixing control (see from Fiedler & Mensing 1985). Therefore, a lower velocity perturbation is usually required which means a smaller amount of energy is used (U.S. Patent '224 col. 2 lines 37 – 42).

Furthermore, the configuration of the method is preferably axisymmetric, i.e. annular or taurus shaped, in other words a shape that is devoid of corners (U.S. Patent '224 col. 3 lines 42 – 46).

Wygnanski concludes that depending on the desired control of mixing, there is a preferred frequency for each case depending on the configurations of the method and velocities of the fluids (U.S. Patent '224 col. 4 lines 41 - 47). Therefore Wygnanski's invention focuses or claims a method for the interaction of the two fluids and the application of an active element (frequency and amplitude) on these two fluids within a boundary that is determined by the velocity of the fluids.

Agent for Applicant respectfully submits that new claim 23 claims a process or method for creating an instability mechanism for rapid and homogeneous mixing of one or more fluids. The result of this method or process is that the creation of the instability mechanism results in enhanced streamwise vortices and dramatically enhanced mixing from the creation of enhanced corner vortices due to the specific geometry of the mixing chamber and the configuration of the splitter plate (passive influences). Furthermore, the application of active forcing of a narrow frequency

band (active influence) on the interactions between these enhanced corner vortices and the primary vortices created by the meeting of the two fluids enhances the mixing even further.

More specifically, the claimed process creates this novel instability mechanism that is not created in Wygnanski as discussed in the following explanation. Through the specific geometry of the mixing chamber and the configuration of one or more splitter plates, corner vortices that normally occur, are further created and enhanced. In other words more corner vortices are created where there is more than one splitter plate, and those that already exist for one splitter plate are enhanced through, e.g. confinement or forcing. As the two fluids enter into the mixing chamber and mix, a shear layer is created between the two fluids by the splitter plate. This shear layer has a certain receptivity to a certain narrow band of frequency. Furthermore, as the two fluids meet, a primary vortex is created at the trailing edge of the splitter plate. Therefore at the trailing edge of the splitter plate the enhanced corner vortices and the primary vortices interact with one another. It is also at the trailing edge of the splitter plate that the narrow frequency band is periodically applied to the shear layer where the two fluids meet or interact. The appropriate frequency is determined by the receptivity of the specific shear layer. This interaction between the corner and primary vortices results in the creation of enhanced streamwise vortices and the further enhancement of the mixing and three dimensional flow of the fluids. As seen in Figure 2c the dramatic mixing has no resemblance to the wedge shape mixing region in Figure 4b of Wygnanski as the mixing rate of the instant invention is twelve times higher than the two fold mixing rate disclosed in Wygnanski. The mixing result in Figure 2b of the instant invention is the same order as that of Figure 4b of Wygnanski.

The creation of these enhanced corner vortices and the resulting streamwise vortices and mixing, is not dependent on the velocity of the two fluids entering the mixing chamber (but on the geometry of mixing chamber and the configuration of the splitter plate or passive influences (page 1, lines 39-45, and page 2 lines 1-6 of specification). Since the corner vortices play an important role in the mixing

enhancement of the claimed invention and are independent of the velocity values of the two fluids, the two fluids can have the same velocity value (if necessary) for mixing enhancement. However, in Wygnanski the two streams have to have a different velocity at the mixing layer. This is because in Wygnanski's invention, the higher the velocity difference for the two streams, the stronger the mixing.

Applying active influences is not always necessary for the claimed invention. In some cases, when the velocity difference of the two fluids is very high, the mean flow velocity is also very high and tube size is sufficiently small, the mixing is very fast due to the initial corner vortices and a secondary flow. More specifically, the secondary flow occurs where the high velocity stream flows to the low velocity stream side in center part of the mixing chamber, and the low velocity stream flows to high stream side along the side wall. Wygnanski does not exhibit any secondary flow without the aid of the active influences (page 2, lines 13-22 of the specification).

As illustrated in Figures 2a-c of the instant application, the spreading angle increases dramatically when this process for creating or enhancing this instability mechanism is applied. Moreover, the instant invention does not have the limitations regarding the velocity of the fluids (discussed above) or the saturation phenomenon as seen in Wygnanski, as the elements required to create the instability (mechanism), i.e. the specific geometry of the mixing chamber and the configuration of the splitter plate, create the streamwise vortices and the enhanced mixing.

One important and apparent difference, between the instant invention and that of Wygnanski is that the narrow forcing frequency band for the new invention does not depend on the mean velocity of the two streams, since the velocity of the fluids is not relevant for creating or enhancing the streamwise vortices for mixing enhancement. This means that once the geometry of the mixing chamber is given, the narrow frequency band for mixing enhancement is approximately a constant and does not need to change even if the velocity of the two streams changes, i.e. there is no restriction on the frequency as seen in Wygnanski (page 2, lines 19-22, of specification).

Although both active forcing and a splitter plate are used in both inventions, they are essentially based on different instability mechanisms. Wygnanski used a now well-known technique, which is based on inherent Kelvin-Helmholtz instability mechanism (col. 2, lines 2-6). In this case, the primary vortices are Kelvin-Helmholtz vortices which rotate only in one direction (positively or negatively) and the centreline of the mixing layers biases to the low velocity stream side. The claimed invention depends not only on Kelvin-Helmholtz instability mechanism, but also a new instability mechanism (see the papers from G. R. Wang 1999 and 2000 noted at the end of the response), which is related to the streamwise vortices, some of which for example are results from the interaction between the vorticity originated from the corner flows between the splitter plate and side wall of the mixing chamber such as a tube, and the vorticity of spanwise structures of the shear layers immediately downstream of the trailing edge. Under a sufficient forcing amplitude of the narrow frequency band on the new instability mechanism, the primary vortices are no more Kelvin-Helmholtz vortices, but counter-rotating vortex pairs. Within each pair, each vortex rotates in opposite directions. The centreline of the mixing layers does not bias to the low velocity stream side anymore, but instead to the high velocity stream side. This new instability plays a very important role in the mixing enhancement, as it not only enhances primary vortices, but also streamwise vortices (which are related to the streamwise corner vortices). However in Wygnanski, only primary vortices are mainly augmented.

There are many different kinds of vortices in the related field. There are even many different kinds of streamwise vortices. It is well known today that the large vortices mentioned by Wygnanski (U.S. Patent '244 Col 3, lines 47-56) are the spanwise (or primary) vortices, but not the streamwise vortices. There could be streamwise vortices in Wygnanski, but they need a sufficient length downstream from the trailing edge of the splitter plate to develop. However, in the claimed invention, first, the streamwise vortices are already extremely strong immediately downstream of the trailing edge of the splitter plate; secondly, the streamwise vortices exhibit themselves differently from Wygnanski, both in how they originate and also how they